

Prehension is really reaching and grasping

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Abstract Prehension has traditionally been seen as the act of coordinated reaching and grasping. However, recently, Smeets and Brenner (in *Motor Control* 3:237–271, 1999) proposed that we might just as well look at prehension as the combination of two independently moving digits. The hand aperture that has featured prominently in many studies on prehension, according to Smeets and Brenner’s “double-pointing hypothesis”, is really an emergent property related to the time course of the positions of the two digits moving to their respective end points. We tested this double-pointing hypothesis by perturbing the end position of one of the digits while leaving the end position of the opposing digit unchanged. To this end, we had participants reach for and grasp a metallic object of which the side surfaces could be made to slide in and out. We administered the perturbation right after movement initiation. On several occasions, after perturbing the end position of one digit, we found effects also on the kinematics of the opposing digit. These findings are in conflict with Smeets and Brenner’s double-pointing hypothesis.

Keywords Prehension · Motor control · Kinematics · Hand · Human

Introduction

Traditionally, prehension has been understood as the act of coordinated reaching and grasping. The reaching component of prehension is concerned with bringing the hand to the object to be grasped, whereas the grasping component refers to the opening and closing of the hand. This suggested division of labor stems from the seminal studies performed by Marc Jeannerod, about 25 years ago, which, for the first time, reported details of the kinematics of prehensile movements (Jeannerod 1981, 1984). Countless studies have addressed all kinds of aspects of prehension, taking this division in components as their starting point. Recently, however, Smeets and Brenner (1999) started advocating an alternative to this view of prehension. They suggested that it is not reaching and grasping that make up prehension, but that the individual digits move independently to their respective sides of the object to be grasped, and that what looks like a grasping component is really something emerging from individual digits’ trajectories. The purpose of the study presented here was to critically test Smeets and Brenner’s “double-pointing hypothesis”. Before presenting the experiment, however, we will briefly review the proposals originally made by Jeannerod and the complaints that Smeets and Brenner formulated regarding the traditional division of prehension into a reaching and a grasping component.

As mentioned earlier, with his first systematic analysis of the kinematics of prehension, Jeannerod (1981, 1984) set the stage for a large number of studies of the control and coordination of reaching and grasping (for reviews, see Castiello 2005; Jeannerod 1988; MacKenzie and Iberall 1994). Jeannerod’s proposal that a reaching (or transport) component and a grasping (or manipulation) component make up prehension was based on a number of arguments, such as anatomical arguments that different muscles and

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brain areas are involved in the control of reaching and grasping (e.g., see Jeannerod 1999; Jeannerod et al. 1995). One of the most prominent among the arguments, however, was that the two components would rely on different types of information about the object: Jeannerod's "visuo-motor channels hypothesis" (Jeannerod 1981, 1988, 1999; Paulignan and Jeannerod 1996) held that the reaching component operates exclusively on information about extrinsic properties of the object (such as its egocentric distance and direction) and the grasping component operates exclusively on information about intrinsic object properties (such as its size, shape, and surface properties). In this sense, the two components (i.e., the two visuo-motor channels) were hypothesized to be independent. This is why many studies designed to test the independence of the two components of prehension involved perturbations of intrinsic object properties, such as size (e.g., Castiello et al. 1993; Paulignan et al. 1991a) or of extrinsic object properties, such as location (e.g., Gentilucci et al. 1992; Paulignan et al. 1991b), to see if the perturbations would have an effect on the component that should not be dependent on information of either object property. Object-size perturbations, for instance, should only affect the grasping component in Jeannerod's model.

With two components making up one act (that of prehension), not only their independence but also their coordination becomes an issue. Most often, when the coordination of prehension has been addressed, hypotheses regarding the moment of peak hand aperture, the moment that hand opening goes into hand closing, have been put forward (for an overview, see Zaal and Bootsma 2004). For instance, it has been proposed that peak hand aperture would occur at the moment of peak deceleration of the reaching movement (Jeannerod 1984), at a fixed time (Gentilucci et al. 1992) or distance (Rand and Stelmach 2005; Rand et al. 2006; Wang and Stelmach 1998, 2001) before hand-object contact, or that coordination is based on time-to-contact information (Bootsma and Van Wieringen 1992; Zaal and Bootsma 2004; Zaal et al. 1998). In our opinion, the latter hypothesis is the most promising of the ones currently available, but it certainly still needs a critical test. To do so, however, the conceptualization of prehension into a reaching and grasping component must be valid. This is where Smeets and Brenner's (1999) hypothesis that prehension should be seen as the combination of independent digit's movements rather than the combination of reaching and grasping becomes problematic. If prehension is not about reaching and grasping, formulating hypotheses about their coordination (or independence) is pointless. This was the direct inspiration for the current study. But before we turn to the experiment that we performed, let us see what made Smeets and Brenner propose a new view on prehension.

Smeets and Brenner (1999) formulated a number of points of dissatisfaction with the original division of labor between a grasping and reaching component as initially proposed by Jeannerod (1981). Smeets and Brenner pointed out that the distinction between intrinsic and extrinsic object properties was problematic. For instance, the orientation of an object could be (and has been) seen both as an intrinsic and as an extrinsic object property. To identify the respective visuo-motor channels on the basis of their exclusive reliance on information about these two types of object properties, Smeets and Brenner argued, was impossible. Furthermore, Smeets and Brenner explained that the anatomical arguments for the distinction of reaching and grasping components were invalid as well. To argue that reaching (hand transport) and grasping (shaping the hand) rely on to the use of proximal and distal muscles, respectively, an argument used by Jeannerod to distinguish the two components of prehension, did not convince Smeets and Brenner, who pointed at the fact that, for instance, pol-yarticular muscles in the lower arm (which are proximal muscles) are involved in movements of the digits.

As an answer to what they called the "classical approach" of Jeannerod (1981), Smeets and Brenner (1999) presented an "alternative approach". Their approach essentially proposes to think of prehension as the independent movement of the contributing digits¹ to their respective planned end positions. These digits, as Smeets and Brenner argued, typically arrive at the surface more or less perpendicularly. If one would look at the average path of the two digits, this would be the straight path that might look like a reaching movement; looking at the distance between the two independently moving digits as a function of time would show the well-known hand-aperture profile (and might be incorrectly interpreted as such, according to Smeets and Brenner). To demonstrate how this control of independent digits looking like reaching and grasping might work, Smeets and Brenner modeled the kinematics of the individual digits with the minimal jerk model (Flash and Hogan 1985), but now with a non-zero deceleration at the moment of digit-hand contact. This latter, final deceleration, scaled by movement time squared, made up an "approach parameter".

Smeets and Brenner demonstrated in their original study as well as in others (e.g., Smeets and Brenner 1999, 2001; Smeets et al. 2002) how by varying the approach parameter and movement time the model fitted empirical data. To appreciate the close resemblance of the model behavior with experimentally established relations among

¹ In most cases, when studying prehension, participants are asked to pick up objects between their thumb and index finger, the, so-called, precision grip. We will discuss the different models with this type of grip in our minds.

“intrinsic” and “extrinsic” object properties and the kinematics of prehension, Smeets and Brenner invited us to translate the average trajectory of the thumb and index finger into a hand transport trajectory and the difference of the trajectories of the thumb and index finger into a grasping trajectory, of course, only for the purpose of comparing the model to observed kinematics. Simulations of the model showed that reaching is not affected by variations in “intrinsic” object properties, that grasping component is not affected by variations in “extrinsic” object properties, that peak hand aperture occurs later in the movement for larger objects, and that an increase in the approach parameter, for instance because a slippery object surface asks for a more perpendicular approach of the digits, leads to a larger peak hand aperture occurring relatively earlier in the movement.

As we discussed earlier, if the hypothesis of Smeets and Brenner’ (1999) is true that it is the digits themselves which are controlled in prehension and not a reaching and grasping component, much of the research on prehension, most notably the studies on the independence of the reaching and grasping component and the studies on the coordination of the two putative components, have been pointless. That is why, we think, a well-funded appraisal of either Smeets and Brenner’s “new view” or of the “classical approach” is called for. Although there have been a number of theoretical and methodological arguments against Smeets and Brenner’s new view (e.g., Marteniuk and Bertram 1999; Newell and Cesari 1999; Rosenbaum et al. 1999; Steenbergen 1999), we felt that an empirical test would be the strongest argument in favor of either approach. This is the reason why we set out to test Smeets and Brenner’s account of prehension. The logic behind our test is the following. If Smeets and Brenner have been correct with their hypothesis that the two digits that are used to pick up an object with a precision grip (between thumb and index finger) move independently to their respective end positions on the object, changing the end position of one of the digits, say, the thumb, would not have an effect on how the other digit, in this case the index finger, would move to its, unchanged, end position. In other words, changing the end position of one digit during the movement should not affect the kinematics of the other digit. For the experiment, we developed an object of which both side surfaces could be made to quickly slide in or out independently (see the Supplementary Movie). We had participants reach for and grasp this object. In some trials, we had one of the two side surfaces slide in or out right after the movement had started, such that one digit had to move to a new position whereas for the other nothing had changed. By comparing the kinematics of both digits with that of unperturbed trials, we were able to test Smeets and Brenner’s hypothesis.

Materials and methods

Participants

Eleven right-handed participants (5 men and 6 women, ranging in age between 20 and 29 years) participated in the experiment. All had normal or corrected-to-normal vision, were naive to the exact purpose of the experiment, and gave written informed consent.

Apparatus

Participants were required to reach to grasp between their thumb and index finger of their right hand an oblong object. The object was located at a distance of 35 cm along the sagittal plane from starting location, which was about 2 cm from the edge of the table. Both side surfaces of the object to be grasped could be slid in or out their common case (see Supplementary Movie). Using pressurized air, this sliding in or out took about 100 ms. The common case was 2 cm high, 4 cm deep, and 4 cm wide. Sliding out one side surface added 1.5 cm to the width of the object.

The long axis of the object was positioned at an angle α with the horizontal along the frontal plane (see Fig. 1). Before the actual experiment was conducted, we had each participant grasp a cylindrical object to determine the angle α that was most natural for the specific participant. This angle was used for that participant throughout the

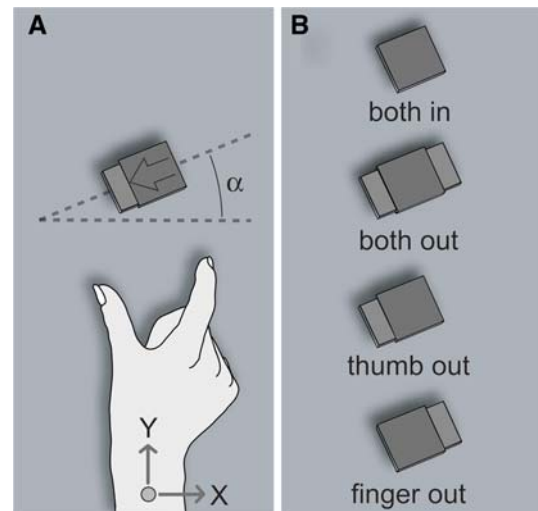


Fig. 1 Overview of the experimental manipulations. **a** Participants were to reach to grasp an oblong object. The orientation of the long axis of the object was at an angle α with the x-axis, the axis perpendicular to the horizontal along the sagittal plane, which was the y-axis. **b** The side surfaces of the target object could be made to slide in or out of their common case. The perturbations yielded a change from one of four possible object configurations to another object configuration. See the text for details

experiment. Angle α varied across participants from 5° to 40° (mostly 20° or 40°).

An Optotrak™ system tracked the positions of infrared light emitting diodes (IREDs) at a rate of 100 Hz. The IREDs were placed (1) on the lateral lower corner of the index finger nail, (2) on the medial lower corner of the thumb nail, (3) immediately proximal to the styloid process of the radius at the wrist, and (4) on the dorsal aspect of the hand immediately proximal to the metacarpo-phalangeal joint of the index finger.

Design and procedure

The participants' task was to reach to grasp the target object as quickly but accurately as possible. The object was not to be lifted at the end of the movement. The experiment started with a block of 80 trials in which the object did not change its configuration during the trial (static block). We randomly presented to the participants the object in one of four configurations (see Fig. 1b): (1) with both side surfaces in their retracted position (static both in), (2) with both side surfaces in their extended position (static both out), (3) with the left side surface slid out and the right side surface slid in (static thumb out), or (4) with the left side surface slid in and the right side surface slid out (static finger out), each configuration 20 times. The static block was followed by a perturbation block, in which in 20% of the 120 trials one of the side surfaces was slid out (or in). The perturbation block consisted of eight types of trials, four in which either side surface slid in or out just after the participant had started his or her movement and the four static configurations that we detailed before (see Fig. 1b). That is to say, the perturbation trials involved (1) trials in which the object changed from a "both-sides-in" to a "thumb-out" configuration (perturbation thumb out), (2) trials in which the object changed from a "both-sides-in" to a "finger-out" configuration (perturbation finger out) (3) trials in which the object changed from a "both-sides-out" to a "finger-out" configuration (perturbation thumb in), and (4) trials in which the object changed from a "both-sides-out" to a "thumb-out" configuration (perturbation finger in).

At the start of each trial, we asked the participants to make the tips of the thumb and index finger of the right hand touch at the starting location. After a signal from the experimenter, the participant was free to choose the moment to start reaching for the object. As mentioned before, in 20% of the trials, randomly interspersed with the static trials, a perturbation of the future end position of one of the digits was administered. This perturbation was triggered by the initiation of the reaching movement of the participant. For that purpose, Optotrak data was used on-line, to compute an average position of the thumb and index finger. After taking the derivative with respect to time of

this position, yielding an average digit speed, we determined the moment that this average digit speed reached a threshold of 20 mm/s. At that moment, a signal was given to move the specific side surface for that condition, after which it took some 100 ms for the side surface to have slid in or out completely.

Data analysis

Data analysis was performed off-line. Because of missing markers or malfunction of the sliding in or out of the side surfaces of the object, we removed eight trials of the static blocks and 31 trials of the perturbation blocks from the data set, leaving us with 2161 trials for analyses. We took out high-frequency noise from the recorded data using a low-pass recursive second-order Butterworth filter at a cut-off frequency of 5 Hz. Next, we computed velocities and accelerations of the IREDs on both digits, using finite-difference techniques. We only considered movements along the x - and y -axes (i.e., the movement components along the horizontal plane; see Fig. 1). The speeds and accelerations that we present are the square roots of the squared speeds and accelerations in x - and y -directions. For each digit separately, we determined the moment its movement started and stopped (we used a speed threshold of 100 mm/s), and the moments of peak acceleration, peak speed, and peak deceleration. In addition, we computed the hand aperture as the distance between the thumb- and index-finger positions and determined the peak hand aperture.

To assess the effect of our manipulations, we concentrated on the moment of peak deceleration² in each digit's reaching movement. For each digit separately, we determined (1) the moment of peak deceleration, and at that moment (2) the amount of deceleration, (3) the speed, (4) the x -position, and (5) the y -position. We compared this quintuple of dependent measures of the trials in which a side surface had been slid out or in with that of the trials of the perturbation block of the corresponding static configuration before sliding in or out had occurred. That is to say, because we were interested to see if perturbing the future end position would have an effect on the kinematics, we compared the perturbation condition with the static condition of the situation as if no perturbation had taken place. For instance, if the perturbation meant a sliding out of the right surface (perturbation finger-out-condition), we compared the trials with such perturbation with the trials of the perturbation block in which all surfaces were in their retract position (both-sides-in condition), which was the initial configuration of the perturbation trials. An effect of the perturbation of targeted end position for a digit would show up

² As will become apparent when we present the results, we repeated the same analyses for the moment of peak acceleration and peak speed.

as a significant effect of the perturbation in the doubly-multivariate analyses of variance (ANOVAs) that we performed. We were specifically interested in effects of the perturbation on the kinematics of the digit on the side that had not been perturbed. All in all, this meant that we performed four sets of two ANOVAs on the sets of dependent measures associated with peak deceleration: for each of the four perturbation conditions, for the thumb- and index-finger kinematics separately, we compared the sets of kinematic variables of the perturbation condition with that of its corresponding static condition of the perturbation block.

Results

As mentioned before, the design of the experiment comprised of a static block, in which the object did not change its configuration during the participant's movement, followed by the perturbation block, in which occasionally one of the side surfaces of the object slid in or out after the participant had started the movement. Table 1 presents the average movement durations and peak velocities of the thumb, and the peak hand apertures of all these conditions. Three things are worth mentioning. First, Table 1 shows that movement durations and peak velocities were essentially the same for the object in all its static configurations. In contrast, peak apertures scaled with the size of the object: peak aperture was smallest when both side surfaces were retracted, largest when both side surfaces were extended, and in between when one of the side surfaces was retracted and the other extended. Second, the same pattern of results can be seen for the corresponding trials of the perturbation block. Finally, movement durations and peak velocities of the perturbation trials were comparable to those of the static trials of the perturbation block. Peak apertures of the perturbation trials were comparable to the middle values of peak apertures of the static trials. This makes sense when we consider that the perturbation always yielded a change to a configuration with one side surface in

its retracted position and the other in its extended position. In sum, nothing was dramatically different between the static conditions of the static block and the perturbation block, and movement durations, peak velocities, and peak apertures of the perturbation conditions were comparable to those of the static conditions of perturbation block. Now, we are ready to turn to the main question that the experiment was designed to answer: did changing the end position of one digit affect not only the kinematics of this digit but also that of the opposite digit?

To assess the effect of perturbing the future end position of each digit, we compared the kinematics of the perturbed situation with that of the situation as if no perturbation would have occurred (the comparisons were made within the perturbation block). For instance, when we looked for an effect of sliding out the thumb side of the object, we compared the kinematics of this situation (perturbation-thumb-out condition; see Fig. 1b) with the kinematics of the situation that both sides remained retracted during the movement (static-both-in condition of the perturbation block). For this comparison, we focused on the moment of peak deceleration of the respective digits (the thumb and index finger). Table 2 gives the kinematic variables that we included in our comparison. We considered the time that peak deceleration occurred, the position of the digit at that moment (x - and y -coordinates), the speed of the digit at that moment, and the amount of deceleration itself.

Sliding out the thumb side of the object had an effect on both the kinematics of the thumb and of the index finger. The comparison of the thumb kinematics of the perturbation-thumb-out condition with that of the static-both-in condition of the perturbation block yielded a highly significant perturbation effect, $F(5,6) = 67.108$, $P < 0.001$. Importantly, however, a perturbation effect was present also in the kinematics of the index finger, $F(5,6) = 6.201$, $P < 0.05$. In other words, sliding out the thumb side of the object did affect the kinematics of the opposing digit, the index finger, for which nothing had changed in terms of the position that it was to be moving to.

Table 1 Means and average within-participant standard deviations (within brackets) of the movement time (MT) and peak speed (PS) of the thumb, as well as peak hand aperture (PA) in the static block and in the perturbation block

Condition	Static block			Perturbation block		
	MT (ms)	PS (mm/s)	PA (mm)	MT (ms)	PS (mm/s)	PA (mm)
Static both in	594 (46)	1103 (79)	89 (5)	587 (43)	1115 (80)	90 (4)
Static thumb out	591 (40)	1097 (67)	99 (4)	591 (41)	1098 (67)	100 (4)
Static finger out	591 (40)	1073 (61)	99 (4)	582 (39)	1082 (68)	99 (4)
Static both out	583 (41)	1087 (63)	107 (4)	579 (37)	1092 (72)	108 (4)
Perturbation thumb out				591 (40)	1106 (78)	99 (3)
Perturbation finger out				582 (45)	1100 (86)	99 (3)
Perturbation thumb in				594 (38)	1096 (68)	96 (5)
Perturbation finger in				606 (42)	1105 (57)	96 (4)

Table 2 Means and average within-participant standard deviations (within brackets) of the time (t), position (x and y), speed (s), and acceleration (a) at the moment of peak deceleration of the thumb and the index finger in the perturbation block

Condition	Thumb					Index finger				
	t (ms)	x (mm)	y (mm)	s (mm/s)	a (mm/s ²)	t (ms)	x (mm)	y (mm)	s (mm/s)	a (mm/s ²)
Static both in	373 (30)	−35 (7)	273 (15)	692 (74)	5209 (832)	395 (36)	32 (8)	324 (18)	674 (111)	5796 (907)
Static thumb out	381 (28)	−33 (6)	275 (16)	666 (78)	5105 (720)	399 (34)	42 (7)	326 (17)	679 (94)	5580 (770)
Static finger out	381 (29)	−45 (6)	269 (14)	660 (74)	5022 (687)	397 (31)	31 (7)	321 (16)	672 (92)	5492 (772)
Static both out	381 (30)	−42 (6)	270 (16)	663 (78)	5100 (779)	393 (31)	40 (7)	322 (16)	698 (89)	5509 (819)
Perturbation thumb out	372 (37)	−37 (7)	269 (16)	700 (92)	4941 (705)	391 (38)	36 (9)	319 (19)	724 (110)	5565 (979)
Perturbation finger out	367 (39)	−42 (7)	262 (17)	690 (94)	5172 (874)	382 (36)	29 (6)	317 (16)	701 (101)	5727 (899)
Perturbation thumb in	376 (38)	−37 (7)	269 (19)	692 (107)	4901 (790)	398 (41)	36 (7)	322 (19)	679 (117)	5589 (911)
Perturbation finger in	369 (25)	−42 (6)	269 (13)	683 (60)	5231 (658)	392 (34)	32 (7)	321 (16)	678 (105)	6501 (787)

Sliding in the index-finger side of the object also led to adaptations of the kinematics of the opposing digit, that is, of the thumb. Comparing the kinematics of the perturbation-finger-in condition with the static-finger-out condition, we found differences in the kinematics of the index finger, $F(5,6) = 6.188$, $P < 0.05$, as well as of the thumb, $F(5,6) = 6.207$, $P < 0.05$.

In the other perturbation situations, we did not find effects of the perturbation on the kinematics of the opposing digit. Sliding out the index-finger surface affected the index-finger kinematics: comparing the perturbation-finger-out condition with the static-both-in condition resulted in a significant perturbation effect on the index-finger kinematics, $F(5,6) = 9.144$, $P < 0.01$, but no significant effect on the thumb kinematics. The comparison of the perturbation-thumb-in condition with the static-thumb-out condition, to look at the effect of sliding in the thumb side surface, yielded no significant perturbation effect on either the index-finger kinematics or the thumb kinematics.

The comparisons to assess the effects of our perturbations were made using doubly multivariate repeated-measures analyses of variance. This method compares, within participants, sets of dependent variables (in the analyses that we presented, a quintuple of kinematic variables determined at the moment that deceleration reached its peak value). Because this method is not a familiar one in the literature, we felt that we had to gauge the power of the method to detect differences, to convince ourselves that the effects that we found were not the result of an oversensitive method picking up random noise. We performed the analyses that we presented earlier, but now on the kinematics at the moment of peak acceleration and at the moment of peak speed. At the moment of peak acceleration, no effect should be found, because this moment is too close to the moment of perturbation. Indeed, none of the comparisons of the kinematics at the moment of peak acceleration yielded a significant perturbation effect. At the moment of peak

speed, we did find significant perturbation effects in two situations. We found a significant perturbation effect when comparing the thumb kinematics in the perturbation-thumb-out condition with the static-both-in condition, $F(5,6) = 7.736$, $P < 0.05$, and also when comparing the thumb kinematics in the perturbation-finger-in condition with the static-finger-out condition, $F(5,6) = 4.487$, $P < 0.05$. These effects amount to finding perturbation effects on the kinematics of the thumb already at the moment of peak speed, which is at about 250 ms into the entire movement of roughly 600 ms, in conditions that also showed perturbation effects later in the movement, at the moment of peak deceleration.

Discussion

Our main finding was that in two of our perturbation conditions, changing the future end position of one of the digits not only had an effect on this digit's own kinematics but also on the kinematics of the opposing digit. This was the case when the thumb side of the object was slid out right after movement initiation, and in the case that the index-finger side of the object was slid in. In both conditions, we found an effect of both the thumb- and index-finger kinematics. This is in direct conflict with the hypothesis of Smeets and Brenner (1999) that prehension is really two digits moving independently to their respective end positions. If this hypothesis would be true, the kinematics of the digit for which nothing had changed in terms of future end position should have remained unchanged as well. This was clearly not the case.

We found the effect of our perturbation in some conditions but not in others. For instance, sliding out the surface on the thumb side had an effect on the thumb kinematics as well as on the index-finger kinematics. The mirror-symmetric perturbation of sliding out the surface at the index-finger side did

only result in an effect on the index-finger kinematics and not on the thumb kinematics. Furthermore, if we found effects of our perturbations on the kinematics earlier than peak deceleration (i.e., at peak speed), these effects were all on the thumb kinematics and never on the index-finger kinematics. One way of interpreting this finding is that thumb and index finger might have a different role in prehension. As proposed earlier by Wing and Haggard (Haggard and Wing 1997; Wing and Fraser 1983), the thumb movement might represent the reaching component of prehension, which would make that the index-finger movement should be seen relative to the thumb movement, and this relative movement would represent the grasping component. Less speculative than this interpretation would be our conclusion that the fact that we did not see the effects of the perturbations in each and every condition, combined with the fact that the kinematic consequences were quite subtle (see Table 2), tells us that the effects that we observed were not the consequence of biomechanical linkages between the digits through a shared hand. If the biomechanical link would be responsible for effects of perturbations showing up in the opposing digit, we would have seen the effects always in both digits or always in none of the digits, and not only in the digit for which the future end position changed.

We did find the perturbation effect on the kinematics of the opposing digit. Therefore, we can reject Smeets and Brenner's hypothesis. Does this mean that we should accept the "traditional" hypothesis then, as proposed by Jeannerod in the early 1980s (Jeannerod 1981, 1984) and adopted by many after those classical studies? Note that the study that we report here was designed to be able to reject the hypothesis of Smeets and Brenner (1999) that the two digits involved in grasping an object with a precision grip move independently to the opposing side surfaces of the object. Technically, this means that we are not in a position to accept the null hypothesis that prehension is functionally organized in a reaching and a grasping component. For instance, one thing that our data did not permit us to demonstrate is that the adaptations of the kinematics of the non-perturbed digit were functional in nature. Future work might focus on showing such functionality of adaptations, much like the work by Kelso et al. (1984), who studied speech production. In their experiment, Kelso and co-workers perturbed the lower yaw of participants who had to produce specific speech utterances. The study showed that a perturbation of the lower yaw was immediately followed by remote compensatory movements of upper lip, but only when that happened to be the functionally appropriate response (i.e., the response that made that the utterance was still produced). This is a nice illustration of how the yaw and the upper lip are functionally coupled. As said, we are not yet in a position to demonstrate the same kind of func-

tional coupling between the thumb and index finger, making up a grasping component of prehension.

When we realize that there is no real other alternative than prehension either being reaching and grasping or being pointing and pointing, rejecting the latter alternative logically would lead to accepting the former. Furthermore, we know from previous studies that hand aperture adapts in a functional way to object-size perturbations (e.g., Castiello et al. 1993; Gentilucci et al. 1992; Paulignan et al. 1991a). Therefore, we conclude that Jeannerod was right after all, and that prehension should be seen as the act of coordinated reaching and grasping. That is not to say, that we believe that prehension is organized in terms of a reaching and grasping "visuo-motor channels" (Jeannerod 1981, 1984, 1999; Paulignan and Jeannerod 1996; see also Arbib 1981; Hoff and Arbib 1993), one operating on the basis of intrinsic object properties and the other operating on extrinsic object properties. We agree with Smeets and Brenner (1999) that the distinction between intrinsic and extrinsic object properties is problematic. Not only can we think of properties that are hard to classify as either intrinsic or extrinsic (Smeets and Brenner mentioned object orientation), but also another literature (in the tradition of, so-called, affordance research; see Gibson 1979; Warren 1984; Warren and Whang 1987) suggests that for the person wishing to pick up an object its size per se is not the relevant variable, but more so its size in relation to relevant body metrics (e.g., Cesari and Newell 1999, 2000a, b; Van der Kamp et al. 1998; Newell et al. 1989; Richardson et al., 2007). For instance, the transition for picking up an object with a two or three-finger grip happens at the same ratio of object size and hand width for small children and adults, such that this transition happens at other object sizes for persons with differently sized hands (Newell et al. 1989). Interestingly, when faced with a series of objects of monotonically changing size, people change their behavior from grasping with one hand to grasping with two hands, even to grasping with two persons, at the same body-scaled size ratio (Richardson et al., 2007). From this perspective, one can impossibly speak of object size to be an intrinsic property. The relevant property has both object and body dimensions as constituents, which would make it both intrinsic and extrinsic. The labeling of object size as being an intrinsic object property seems off. That is not to say, however, that grasping does not rely on specific information to be controlled. We are convinced it does. In our mind, prehension is reaching and grasping, both controlled on the basis of specific information, but reaching and grasping are not tied to intrinsic and extrinsic object properties.

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